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Dynamic Characteristics Study of Belt Conveyor Based on Virtual Prototyping

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Abstract: With the improvement of the load and speed of belt conveyor, the dynamic characteristic problem of belt conveyer appears especially outstanding. This paper analyzed the force situation of the conveyer by the discrete dynamics model, divided n viscoelastic properties mass units in advance, then built system analysis dynamics model by vibration mechanics, built modal neutral file of the flexible belt block by means of finite element analysis software, and built the virtual prototype model of the belt conveyor using ADMAS program. It analyzed the effect of stiffness and damping of belt on the starting process by dynamic characteristics simulation method. The simulation results showed that the speed wave period of belt with the smaller stiffness was longer and the peak was bigger, the belt speed easily occurred stronger surge, the transverse vibration of belt conveyor became more violent. With the increasing of stiffness, the belt speed wave peak value decreased. As the same time, the speed surge also decreased when other operation parameters of the belt conveyer system are fixed, with increasing of the damping, the dynamic tension force peak became smaller gradually, it led to decrease of vibration curve peak. Damping coefficient played the important role in decreasing the vibration intensity, the research result offers a new basis for the analysis and study of the dynamic characteristics of belt conveyor.

Introduction

Belt conveyor ,which develop towards the deriction of the long-distance, high belt speed and large capacity, is putted forward a higher demand for its dynamic characteristics in design [1-2]. Nowadays the dynamic characteristics study of conveyor are mainly concentrated on the independent research,such as the non-stable condition, the dissemination of dynamic tension, the longitudinal vibration and lateral vibration [3-4], and there are still some limitations in the study of dynamic performance of conveyor . In this paper, the virtual prototyping technology is introduced into the dynamic characteristics analysis of conveyor, and ADAMS software is to be used in the simulation analysis of dynamic characteristics, thus a new analytical method and means is provided for the dynamic characteristics study and design of conveyor.

The Establishment of Virtual Prototype Model of Belt Conveyor

The Simplification of Belt Conveyor System.

Mechanical system of conveyor is mainly made of drive set, conveyer belt, carrier rollers and rack, tensioning device, etc, compared with the conveyor belt, the stiffness of drive roller, divert drum, rack and carrier rollers is relatively large, and its deformation is very small, it can be regarded as a rigid body, therefore, in the conveyor parts, with the exception of the flexible conveyor belt is

regarded as flexible body, the remaining components are treated as rigid body. At the same time, in the establishment of virtual prototyping system of conveyor, the rack fixed on the ground not moving, it will be simplified to connect fixed to the ground, the driven devices to be simplified a overall rigid body, and does not consider its deformation, the definition of functions is used to compensate for its impact only when input the driven, and can considerate it according to their comprehensive startup curve (speed curves started by HARRISION in this article). Therefore, the model to be simplified for the conveyor belt, drive roller, divert roller, tensioning device, rack and other parts, and the driving force will be directly added to the driving drum, the drive roller's position is putted in the head of the system; The divert drum can be offered doing the longitudinal movement, and then it will be simplified to two rigid body composed of the transmission roller axis and rotation around the axis of the cylinder in the model being simplified; The tension force roles to the rear drum divert axis, that is, imposes a preload to the built model; Constant tension using gravity method for solving convenience, and the device directly simplified as power, and added to the axis cylinder of divert; Driven devices will be simplified into a driving torque, and acts on the drive drum.

The Establishment of Geometric Model of Belt Conveyor.

It has three ways to realize the geometry model of virtual prototype conveyor. ① completed in the ADAMS environment; ② established the geometric model and lead it into ADAMS environment in PRO / ENGINEER through Mechanism / Pro module; ③ modeled in the UG environment, then imported into ADAMS environment by the motion of module UG. However, the interface has aperture in ADAMS and other CAD software, which inevitably existence the problem of the information's lost in the transfer process. Therefore, the geometric model is established in ADAMS environment as far as possible while it is easier to be established in the ADAMS environment, and this article is directly established in the ADAMS environment.

Simplification of Flexible Model of Conveyor Belt.

As the conveyor belt itself is flexible body, there are two ways to build-up models in ADAMS: One is dividing the belt into many small pieces, and then impose constraints between the various pieces to fit the deformation and flexible, similar to the finite element ideas; The second method is enabling the conveyor belt with a viscous-elastic by the flexible body theory provided by ADAMS. This method can be completed by three ways, ①to be completed by flexible modules ADAMS / FLEX provided by ADAMS; ② the user write a modal neutral file using the finite element knowledge, and then enter the text in the ADAMS; ③to make modal neutral file by using the finite element software, and then imported it into ADAMS [5-6]. In this paper, the modal neutral file of pieces of soft belt of model is created through the use of ANSYS finite element analysis software.

The Establishment of Dynamics Equations of Belt Conveyor.

Due to the viscous elasticity properties of conveyor belt, the performance of mechanical properties is non-linear in the course of conveyor running, and analyses the belt conveyors' stress by the discrete dynamic model, and establishes the dynamic models of belt conveyor. Conveyor system will be divided into *n* quality units with the viscous elastic properties in advance, and then establish the dynamic model using the method of mechanical dynamic analysis, the figure 1 is the discrete dynamic model of conveyor system, and obtains the dynamics equations of a belt conveyor

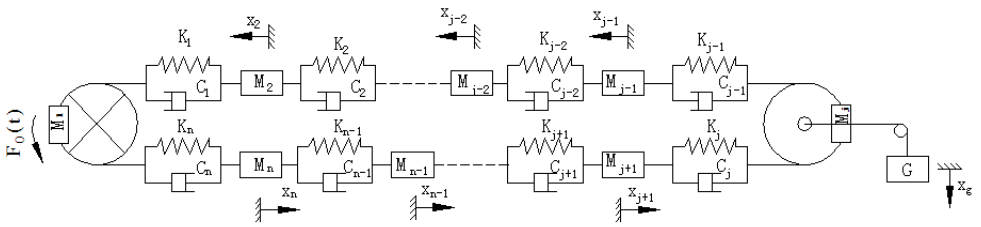


Fig. 1 The conveyor dynamic model

based on the relationship of the particle mechanics as follows:

$$
\begin{aligned}
&m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_2) + c_n(\dot{x}_n - \dot{x}_1) + k_1(x_1 - x_2) + k_n(x_n - x_1) = F_0(t) - F_1'(t)\\
&m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_3) + c_1(\dot{x}_2 - \dot{x}_1) + k_2(x_2 - x_3) + k_1(x_2 - x_1) = -F_2'(t)\\
&\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\\
&\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\\
&m_{j-1}\ddot{x}_{j-1} + c_{j-1}(\dot{x}_{j-1} - \dot{x}_j + \dot{x}_g) + c_{j-2}(\dot{x}_{j-1} - \dot{x}_{j-2}) + k_{j-1}(x_{j-1} - x_j + x_g) + k_{j-2}(x_{j-1} - x_{j-2}) = -F_{j-1}'(t)\\
&m_j\ddot{x}_j + c_j(\dot{x}_j - \dot{x}_{j-1} + \dot{x}_g) + c_{j+1}(\dot{x}_j - \dot{x}_{j+1} + \dot{x}_g) + k_j(x_j - x_{j-1} + x_g) + k_{j+1}(x_j - x_{j-1} + x_g) = mg - F_j'(t)\\
&m_{j+1}\ddot{x}_{j+1} + c_{j+1}(\dot{x}_{j+1} - \dot{x}_{j+2}) + c_j(\dot{x}_{j+1} - \dot{x}_j + \dot{x}_g) + k_{j+1}(x_{j+1} - x_{j+2}) + k_j(x_{j+1} - x_j + \dot{x}_g) = -F_{j+1}'(t)\\
&\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\\
&\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\quad\cdots\\
&m_n\ddot{x}_n + c_n(\dot{x}_n - \dot{x}_1) + c_{n-1}(\dot{x}_n - \dot{x}_{n-1}) + k_n(x_n - x_1) + k_{n-1}(x_n - x_{n-1}) = -F_n'(t)
\end{aligned}
\qquad (1)
$$

Where $F_0(t)$, $F_i'(t)$——Respectively, driving force for the conveyor and the resistance of units;

k_i, c_i—— Respectively, stiffness coefficient and damping coefficient of each unit;

x_i, x_g—— Respectively, for the synthetic displacement of rigid movement and elastic deformation of the conveyor belt units or tighten heavy weight.

Collated and written in matrix equation form as follows:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F(t)\} \quad . \qquad (2)$$

Where [*M*], [*C*], [*K*]——Respectively, for the unit mass matrix, damping coefficient matrix and stiffness coefficient matrix;

$\{\ddot{x}\}$, $\{\dot{x}\}$, $\{x\}$——Respectively, for the column vector of acceleration, velocity and synthetic displacement.

The Determination of Size And Parameters of The Model of Conveyor Virtual Prototype.

The simplified geometric model of belt conveyor only contains the head drive roller, tail roller divert, divert roller axis, carrier roller and conveyor belt. Specific parameters are as follows: the diameters of drive roller and divert roller are offered $D = 1400\text{mm}$, and materials are steel (rigid material)，carrier roller's diameter $d = 108\text{mm}$, space of carrier roller in carrying l_g'=1.2m, back to space idler spacing l_g"=3.0m, transport length of belt conveyor L=500m; Conveyor belt model ST-1250, conveyer belt width $B = 1000\text{mm}$, stiffness coefficient $k = 8.125 \times 107\text{N/m}$, damping coefficient c=1.67×105Ns/m, line density of conveyer belt q_d=24.5kg/m q_d=24.7kg/m, conveyer belt thickness $\delta = 22\text{mm}$; The friction coefficient between drive roller and conveyer beltμ=0.35, the friction coefficient between divert rollers and conveyer belt μ_1=0.3; Conveyer belt initial tension *F*=50kN; constant tension, normal working speed of conveyer belt v_0=6m/s. Based on the above parameters, the virtual prototype model of belt conveyor is established as shown in figure 2 and figure 3.

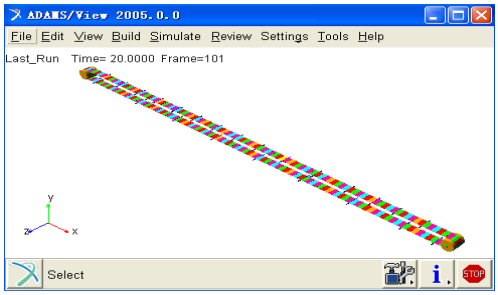


Fig.2 Virtual prototype solid model of conveyor

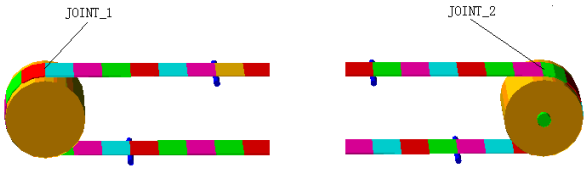
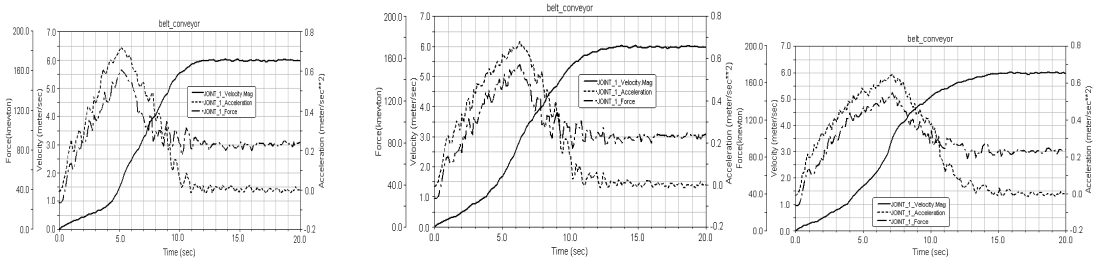


Fig.3 Local enlarge model of virtual prototyping

The Simulation Analysis of Dynamic Characteristic of Belt Conveyor

The Influence On Dynamic Characteristic of Starting Time of Belt Conveyor.

The dynamic tension of belt conveyor is generally reached its peak in the start-up phase, so it has the important meaning to study the rule of dynamic tension change and the influence factors of starting process. As shown in figure 4, the change process of conveyor belts' acceleration in the different starting time and tension changes is given while gives the throughput $Q=400t/h$ and carries on the start according to the harrision velocity curve, finally, the running velocity achieves v_0=6m/s. In the chart, the solid line expresses the velocity curve that on the transmission drum place conveyor belt connects the vice-JOINT_1 local, the dot dash line expresses that the point of tension curve, the dashed line expresses the point of acceleration curve. From figure 4 (a), (b) and (c) can be seen, in the starting process, when $T=10\text{s}$, the biggest tension value reaches 160.2kN, the stable tension value is 89.1kN, the maximum acceleration reaches 0.72m/s^2, correspondence the time of speed-up $t=5.1\text{s}$, when the speed achieves 6m/s, the acceleration tends to zero; when $T=12\text{s}$, the biggest tension value reaches 155.4kN, the maximum acceleration reaches 0.67m/s^2, correspondence the time speed-up $t=6.2\text{s}$; When $T=14\text{s}$, the biggest tension value reaches 152.7kN, the maximum acceleration reaches 0.64m/s^2, correspondence the time of speed-up $t=7.1\text{s}$. As can be seen, the largest peak acceleration occurs in the corresponding acceleration time to start nearby the T/2. The static tension is 123.5kN, the maximum dynamic tension increases 29.7% compare with the static tension. Through the comparative analysis of belt conveyer's dynamic characteristic of start-up phase under the different starting time in figure 4, the relationship between dynamic parameter and length of starting time is given in figure 5, and it can be seen from the chart that the length of starting time has the following influence to conveyor belts' dynamic characteristic: □the peak dynamic tension is usually showed-up at the time near the largest acceleration and with the start-up time lengthened to reduce (it is proportional approximation to the maximum of acceleration), but the reduction of tension peak significantly change ease after the start-up time reaches the rated speed; ②Starting time's extension may cause the reduction of the tension fluctuation peak-to-peak value while starting conveyer belt; ③ the dynamic tension of the conveyor belt converges in the one whose tension value is basically the same size with the start process' over, it indicates that starts acceleration curve only affects the dynamic tension of the boot process, and does not affect the tension of the conveyor in the normal operation. Therefore, it should be appropriately increased the start-up time to reduce the dynamic tension of a conveyor belt when the conditions permitted in order to improve the operation security of the conveyor belt, and lengthen the conveyor belts' service life.



（a）T=10s （b）T=12s （c）T=14s

Fig. 4 The curve of speed, tension and acceleration in startup procedure

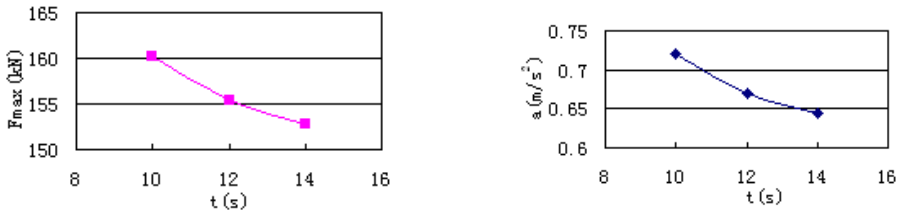
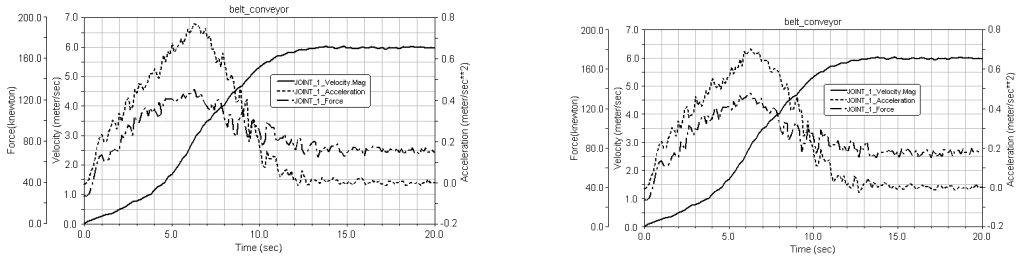


Fig. 5 The relationship of dynamic characteristic and starting time of conveyor belt

The Influence On Dynamic Characteristic of Conveyor Capacity of Conveyor.

The conveyor capacity is one of the main factors to determine the drive power of belt conveyor, when the conveyer's conveyor capacity is different, its dynamic characteristic is also different. Figure 6 is a time-varying tension curve of virtual prototype conveyor which transmission roller department connector JOINT_1 by point of conveyor belt where the start acceleration time is T=12s, the running velocity is v_0=6m/s, and virtual prototype conveyor operates in different conveyor capacity. In the chart, the solid line expresses the velocity curve of transmission drum spots, the dot dash line expresses the tension curve of the point, the dashed line expresses the acceleration curve of the point.



（a）No-load （b）Q=200t/h

Fig. 6 The curve of speed, tension and acceleration of the starting process

It can be seen from figure 6 (a) and (b), the maximum tension value reaches 127.9kN on the starting process in no-load, the tension value of the normal operation is 69.1k, the static tension value is 102.7kN, the maximum acceleration reaches 0.78m/s^2; when the conveyor capacity Q=200t/h, in the starting process, the maximum tension value reaches 138.2kN, the tension value is 78.5kN in normal operation, the static tension value is 110.7kN, the maximum acceleration reaches 0.71m/s^2. The figure 7 has given the change situation of the identical disposition of belt conveyor about the amount of acceleration of drive roller and dynamic tension of tight side of drive roller in different conveyor capacity (—■— expresses the static tension, —◆— expresses the movement tension, —▲— expresses the biggest tension).

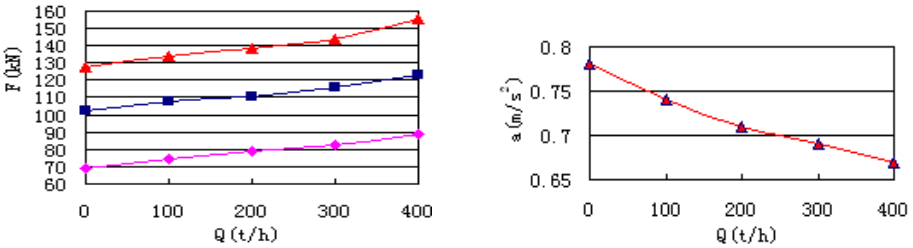


Fig.7 The influence on the belt conveyor in different conveyor capacity

The change of conveyor's acceleration curve is basically the same when the conveyor capacity is different, according to the acceleration curve of transmission drum, but the peak-to-peak value of vibration is bigger when conveyer in light loading. The changing curve of kinetic tension shows that the conveyor capacity can influence in the tension peak value and the normal operation tension value of the conveyor belt, and it is basically the same as changes in amplitude, therefore, it can obtain the dynamic tension peak size of other convey capacity of conveyer belt by computing the size of the conveyor capacity on the basis of the curve of dynamic tension changed in a transmission, in order to determine a reasonable safety factor of conveyor belt.

Conclusion

Through the analysis of changing curve which the acceleration produced in the startup and the dynamic tension along with the time showed that the drive type of startup procedure has the biggest influence to dynamic characteristic of the conveyor belt, and the maximum dynamic tension occurred in nearby the T/2 of start-up time, using the reasonable initialization mode and the corresponding extension starting time can reduce the conveyor belts' vibration effectively, and improve the dynamic property of belt type conveyer; Through the analysis of the changes of throughput indicate that the tension change curve in different conveyor capacity, may obtain the magnitude of the dynamic tension curve’s peak value of other conveyor capacity of the conveyor belt, in order to determine a reasonable safety coefficient of a conveyor belt.

The main purpose that researches the dynamic characteristics of the conveyor is to reduce the dynamic tension peak of conveyor belt in started moving, in order to improve the safety of belt conveyor, and to ensure the safe operation of conveyor in the lower safety coefficient. Therefore, the research of dynamic characteristic simulation by the model of conveyor virtual prototype established by the ADAMS software will help to enhance the speed of belt conveyor in ensuring the safety running of the conveyor, and raise the transportation productivity. It is also helpful to research the belt conveyer dynamic design, and promote the belt conveyer dynamic design level increased.

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